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TURBIDIMETRY OF WATER[1]

By P. V. Wells[2]

The famous experiment of Tyndall, which explained the blue color of the sky, was to focus in a narrow pencil the extremely powerful light from an electric arc, and to examine the "Tyndall beam" from the side, against a dark background. The young Lord Rayleigh has recently measured in this manner the light scattered by gas molecules themselves. Such light is of a saturated blue color and the theory of the late Lord Rayleigh indicates that its intensity (I) increases with the size of particle according to the relation

$$\frac{I}{I_0} = k\frac{C\,x\,d^3}{\lambda^4} \quad (d << \lambda) \tag{1}$$

where (I_o) is the original intensity, (C) the concentration of the particles of diameter (d), (x) the depth of beam and (λ) the wave length of the scattered light.

This formula holds only for particles vanishingly small compared with the wave length of light. But water analysts are concerned mainly with coarser suspensions, the muddy appearance of which is due not to scattered light but to reflected light. The intensity of light reflected by coarse particles increases in proportion to their total surface, so that

$$\frac{I}{I_0} = k\frac{C\,x}{d} \quad (d >> \lambda) \tag{2}$$

This agrees with the experimental fact that smaller particles give higher turbidities in ordinary suspensions.

The transition from diffuse reflection to scattering occurs in the region of the wave length of light. Mie finds this to occur at (d = $\lambda/3$ to $\lambda/4$) which is just about the limit of resolution of particles in the microscope. Hence we may combine equations (1) and (2) in a single formula,

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[1] Read before the Chemical and Bacteriological Section, at the Cleveland Convention, June 9, 1921.

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$$\frac{I}{I_0} = k \frac{C x d^3}{d^4 + 0.002 \lambda^4} \tag{3}$$

Instruments which measure the intensity of the Tyndall beam are usually called *tyndallmeters*, and are most sensitive for very small turbidities. Thus Richards' nephelometer is a comparison form of tyndallmeter.

For over a hundred years the oceanographer has lowered circular discs of canvas into the sea to measure the transparency of sea water, and the turbidity standard of water analysis does not differ in principle from this method. The theory of the disappearance criterion is very complicated, but as an empirical method it is remarkably simple, free from disturbing factors, and reproducible. Instruments based upon the disappearance method are usually called *turbidimeters*.

Turbidity is expressed as a concentration (parts per million, or milligrams per liter), but the concentration cannot be measured directly, either by a tyndallmeter or by a turbidimeter. In fact both these instruments measure a complicated function of the concentration, the size of particles, and density constants of the dispersed and continuous phases, to say nothing of secondary factors. A single observation, such as turbidity or tyndall-intensity, cannot be expected to specify with any completeness a complicated and variable suspension or any other type of dispersoid.

In order to gain some impression of the complicated nature of a dispersoid, consider a standard silica suspension of 100 parts per million (10^{-4} = 100 milligrams per liter). Suppose this suspension to be composed of spheres of perfectly pure silica dispersed in pure water, and of uniform diameter 1 micron = 10^{-4} cm. In order to produce this concentration about 10^8 = 100,000,000 particles per cubic centimeter are required, and although these particles occupy less than one-thirty-thousandth of the volume, they present a surface of over one square centimeter per cubic centimeter. They are on the average about 2×10^{-3} cm. = 20 microns apart, and diffuse this distance in about eight minutes, because of the incessant Brownian agitation. Carried about by convection currents and by diffusion, the particles are continually coalescing to form larger aggregates, unless some force such as electrostatic repulsion keeps them separated. Hence the suspension, initially uniform, soon contains larger particles which settle out more rapidly. But in practise the particles are distributed in size and are further covered with adsorbed layers of various impurities, etc., presenting an extremely complicated system. These complications seriously retard progress in the systematic study of dispersoids.

One of the simplest means of specifying the size distribution of the particles forming the dispersed phase in the "settling curve." A tyndallmeter is quite appropriate for this purpose, the tyndall-intensity being read at equal logarithmic intervals of time. It possesses the advantage of sensitiveness over the Odén balance method. Changes in tyndall-intensity corresponding to the settling out of masses quite beyond the possibility of weighing are easily measured. Moreover the sample can be enclosed and evaporation prevented, and the effect of humidity in changing the apparent weight does not enter as a disturbing factor. But the interpretation of the observed quantity (tyndall-intensity) is not so direct as that of the balance method (total mass settled out). The possibilities of the method are now being tested.